IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received October 28, 2019, accepted November 8, 2019, date of publication November 29, 2019,
date of current version December 23, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2956835

Research on Intelligent Monitoring and Analysis of Physical Fitness Based on the Internet of Things

ZEJIANG HUANG[1], QINGGUO CHEN[1], LIFENG ZHANG[2], AND XIAOHAI HU[3]

[1]College of Physical Education of Sichuan Normal University, Sichuan Normal University, Sichuan 610101, China
[2]College of Physical Education and Training of Second Department, Chengdu Sport Institute, Sichuan 610041, China
[3]College of Physical Education College of Zhengzhou University, Zhengzhou 452470, China

Corresponding author: Xiaohai Hu (huxiaohai@peczzu.edu.cn)

This work was supported in part by the National Social Science Foundation of China under Grant 18BTY101.

ABSTRACT In the process of physical fitness training, it is an important subject of scientific physical fitness training to adjust and control the physical load intensity in real-time, accurately and effectively according to the physiological load inside the human body so as to make it consistent with the predetermined goal of the training plan. Aiming at the current demand of smartphone popularization and athlete training monitoring, this paper designs an intelligent monitoring system of physical fitness based on the Internet of Things technology. By selecting such factors as vertical jump, fast leg raising, sitting forward, height, chest circumference, percentage of body constitution, YOYO intermittent endurance running and so on, using RFID technology to mark different athletes, and after using the particle swarm optimization method of BP network to establish the evaluation model of the athletes' physical condition. Through simulation, the physical condition of athletes is accurately predicted, which provides a new scientific and technological means to improve the efficiency of physical training and make physical training scientific.

INDEX TERMS Physical fitness, intelligent monitoring, The Internet of Things, BP neural network, particle swarm.

I. INTRODUCTION

With the development of national economy and the improvement of people's living standards, people pay more and more attention to their healthy development, and the wave of national fitness is gradually flourishing [1]. Sports events as one of the activities to show the level of national physical fitness and health in all countries of the world, achieving excellent results are the ultimate goal of athletes'training and competition [2]. By testing the athletes'physical condition, we can give full play to their athletic ability and achieve excellent results. For the physical fitness test of athletes, the testing methods and analysis methods of all countries in the world are constantly improving and developing.

The traditional way of physical fitness test is that the coach records the athletes'physical fitness test results regularly, evaluates the athletes' physical fitness status through comprehensive results, and specifies the next training plan [3].

The associate editor coordinating the review of this manuscript and approving it for publication was Honghao Gao.

Kietzmann T [4] studied the effect of intensive training on the stability and instability of surface physical fitness of preadolescent football players, and used ANCOVA model to analyze the results of physical fitness test. Zhao *et al.* [5] analyzed and discussed the rationality and validity of the physical fitness test content and standard of Sanda athletes by means of the test method and multivariate statistical method, and established the evaluation criteria for the physical fitness test of Sanda distant mobilization. Woods *et al.* [6] made a basic sports evaluation of Australian young athletes. By testing the basic movements, the non-parametric correlation matrix of Spearman was established, and the correlation coefficient was visualized by using the correlation graph presented by the cycle, which provided help for the selection of athletes. With the development of computer technology and the Internet of Things technology, through the establishment of appropriate database, data storage, extraction, association and analysis can provide accurate information data for athletes'training programs to assist coaches in management. Yang [7] established a database system, which inputs the physical fitness

test process and the result data of table tennis players into the system. Through optimizing the database management mode, output the key physical fitness index system, and feedback to the coach to formulate the corresponding training program, thereby improving the training efficiency and quality of athletes. For the development of physical fitness testing system, Miller *et al.* [8] developed an RFID system for aerobic cardiovascular endurance running and a 6-minute walking test, which is a common tracking and tracking technology and plays an important role in the field of sports testing. Tseng *et al.* [9] have studied a comprehensive physical fitness testing system for the elderly. The system consists of four modules to evaluate the health status of users. The testing information will be recorded and managed through wireless sensor networks in order to better understand the health status of users. Huang *et al.* [10] developed an intelligent execution scheduling system for specific fitness and health care systems. Using fuzzy logic reasoning, test results of health care systems are automatically generated, and scheduling schemes are generated by genetic algorithm, which effectively improves people's system health management system. Traditional physical fitness testing methods have many problems, such as the huge amount of data, complex manual management and so on. It can provide important conditions for physical fitness monitoring by building the database and portable equipment.

In this paper, portable sensors and RFID technology are used to monitor athletes 'physical fitness in real-time. By building an intelligent physical fitness monitoring system on the Internet of Things, athletes' physical fitness testing information is stored and classified, and the BP network method is used to analyze the correlation of data. Which can provide users and coaches with a high matching training program, make athletes 'physical fitness test develop towards a scientific and regular direction, give full play to athletes' competitive potential and improve athletes 'physical fitness.

II. CONSTRUCTING THE INDEX SYSTEM OF PHYSICAL FITNESS TESTING

Athletes 'physical fitness determines their competitive level, so the competitive level is the most important factor to achieve sports results. Getting the real-time physical fitness of athletes plays an important guiding role in the whole sports training and competition activities. It is the direct expected goal of all kinds of work, that is, the objective condition for scientific diagnosis of training and competition effect, and the important basis for scientific control of training and competition process [11].

At present, the definition of physical fitness at home and abroad is mainly divided into two aspects, one is broad physical fitness, the other is narrow physical fitness. The generalized physical fitness refers to the basic form, function and sports quality of the human body [12]. The narrow sense of physical fitness is the embodiment of special ability represented by special sports quality. Therefore, special quality is the core of physical fitness, form is the external structure

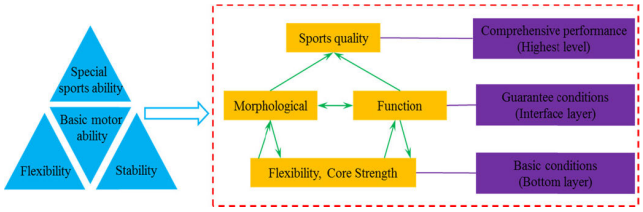

FIGURE 1. Hierarchical chart of action mode elements and physical fitness elements.

of physical fitness, and function is the internal reflection of physical fitness [13]. According to the definition of physical fitness operability, physical fitness is defined as: physical fitness takes shape as its external characteristics, function as its internal function, and sports quality as its core content to maintain the human body's ability to bear load and adapt to the environment. According to the division of the structural elements of physical fitness, it is considered that the main structural elements of physical fitness are morphology, function and sports quality, and the core embodiment of physical fitness is to highlight the sports quality. The structural elements of physical fitness are shown in Fig. 1

The idea of action mode was put forward by Mike Boyle, an authoritative American expert on physical fitness. The idea of action mode is based on flexibility and stability. Flexibility and stability should be trained first in physical fitness training, and then it should be transferred to specific quality training. Flexibility and core are the key elements of physical fitness structure in this paper. Athletes 'cardiac strength is the foundation, and their sport quality is the highest performance. Morphology and function are the guarantee conditions of physical fitness [14], [15].

For competitive sports, the ultimate goal of sports training is to create excellent sports results, and the physical fitness of athletes is the most basic and controllable factor to improve competitive ability [16]. Physical fitness test is the basic way for coaches to understand the physical fitness of athletes. Coaches should regularly carry out physical fitness tests on athletes, convert the results of each athlete's physical fitness tests according to different test standards, then evaluate the athlete's physical fitness status according to their own experience, and formulate corresponding training programs to guide training. However, with the accumulation of test data, it has become more and more difficult to manage and analyze these data by manual processing. By using the traditional data processing and database management functions of the computer, we can solve the management problem of physical fitness test data, help coaches to manage athletes, sports performance conversion, historical data management and other aspects, and improve the efficiency of data processing. However, it cannot solve the scientific evaluation and prediction of the physical condition of sports, and cannot discover the knowledge hidden behind the data resources [17].

Traditional data analysis and processing methods only analyze the local or surface characteristics of the data, but cannot get the description of the overall characteristics of the

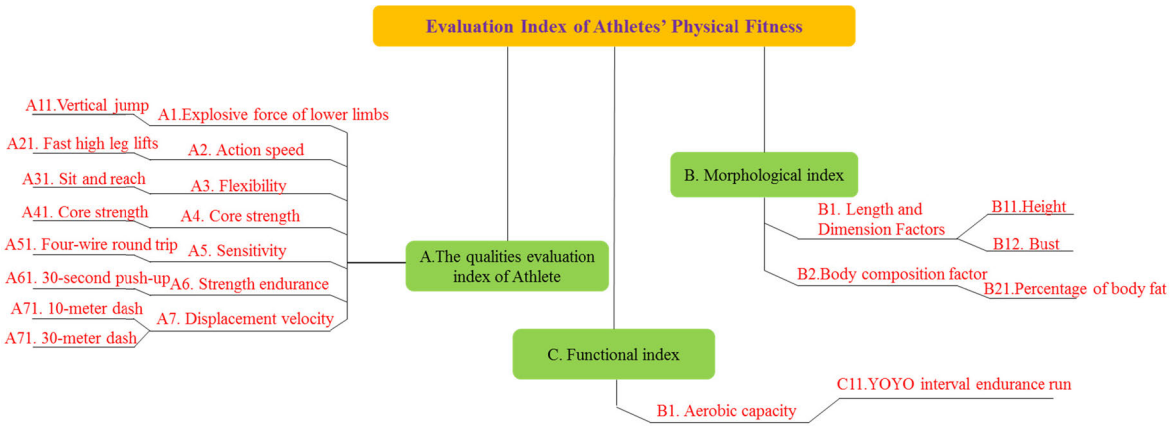

FIGURE 2. Comprehensive physical fitness evaluation index system.

data hidden behind the data and the prediction information of its development trend. Physical condition evaluation and prediction are concerned with the important information hidden behind these data. Data mining technology can extract valuable, previously unknown, implicit and potentially useful knowledge from a large number of raw data. Therefore, it is very suitable for the analysis of athletes 'physical fitness test data. At present, the more widely used method is to rely on the experience of coaches to adjust the athletes 'physical condition to the best through adjusting and intensifying training during the preparation of competition. This requires coaches to have rich training experience, and fully understand the physical condition of athletes. Obviously, this increases the pressure on coaches to make decisions and the possibility of making mistakes. Through these historical data analyses, we can find out the development and change rules of athletes 'physical fitness state, predict athletes' physical fitness state in a certain period, and provide the scientific basis for coaches to make training plans. The first condition to solve this problem is to construct the index system of athletes 'physical fitness evaluation [18].

Physical fitness test index is an important reference to reflect athletes' competitive ability, and is also the core of the evaluation. The representativeness and validity of indicators determine the reliability and practicability of test data. Screening and determining indicators is the primary task of evaluation and is also an important factor affecting the whole evaluation results. By reading the predecessors' research of physical content, inductive conclusion predecessors study mainly from three aspects of fitness, combining with the above certain actions and hierarchical relationships on the basis of the physical elements, from the three of quality, form and function of the movement of athletes in the face of the athletes' physical fitness evaluation, finally constitute three first-level indicators, 10 second indices and 12 athletes physical ability evaluation index system of three indicators, as shown in Fig. 2.

The height of an athlete has a certain influence on his sports ability. Taking ball games as an example, tall athletes have certain advantages in the control of the ball in the air to expand the effective control range. The wide chest circumference of athletes is conducive to maintaining a reasonable physical confrontation in sports. The percentage of body fat reflects the rationality of the athlete's form. The lower the percentage of body fat, the more muscle and less fat the athlete has. Too much body fat will increase the weight of athletes, affect the ability to run in sports and complete technical movements. A reasonable percentage of body fat is an important condition for athletes to improve their performance [19].

III. DESIGN OF PHYSICAL ABILITY INTELLIGENT MONITORING SYSTEM BASED ON THE INTERNET OF THINGS TECHNOLOGY

Through the establishment of index system for athletes' physical fitness monitoring items, athletes' physical fitness information can be collected pertinently and then effectively correlated and analyzed. Among them, the information monitoring platform and data analysis are important links. Therefore, the construction of physical intelligence monitoring system that based on the Internet of Things technology has real-time convenience for athletes to obtain their own information.

A. PRINCIPLE AND APPLICATION OF THE INTERNET OF THINGS TECHNOLOGY

As the most important component of the new generation of information technology, the Internet of Things was proposed by an American professor in 1999. It has developed from the initial radio frequency technology, sensor equipment, etc. to the current embedded system, cloud computing and other intelligent technologies with high-tech level [21]–[23]. The main purpose of the Internet of Things is to realize intelligent identification, location, tracking, monitoring and management of objects. By using the Internet of Things technology, people can use any The Internet of Things network to exchange information with any person and object. The working principle of the Internet of Things is to connect various objects with the Internet according to a prescribed

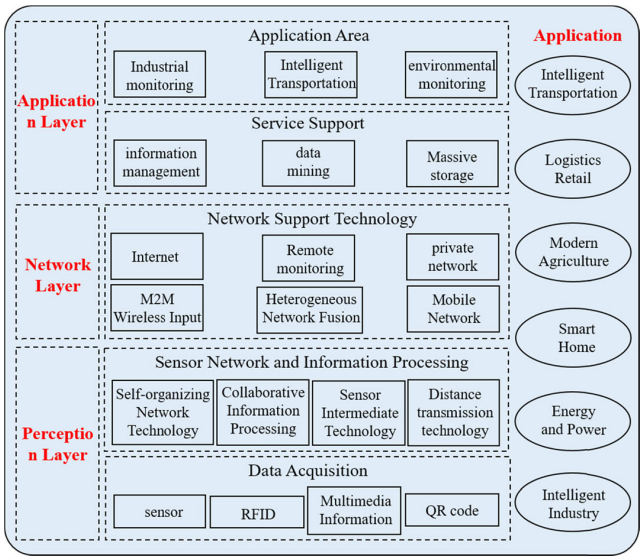

FIGURE 3. Basic architecture and application of the internet of things technology.

protocol through information storage devices to complete the exchange and communication of information and data, such as radio frequency identification (RFID), global positioning system, infrared sensors, laser scanners, etc.

The organizational structure of the Internet of Things generally consists of three parts, namely, the perception layer, the transport layer and the application layer [24]. The sensing layer is formed based on the combination of various types of sensors and sensor gateways. Sensors, two-dimensional codes, radio frequency devices, etc. Through detecting and sensing the information of objects, valuable information is screened out by using short-range transmission technology, cooperative processing technology, etc. Finally, data collection and precision improvement are completed.

The transport layer is also called the network layer. Its function is to transmit the information and data collected by the perception layer to the network, thus helping users to realize the application and control of objects. In the process, the sensing data is first connected to Ethernet, wireless network or satellite cluster, and then transmitted over a long distance by using mobile communication network, Internet or private network [25].

The application layer is the interface link between the The Internet of Things and users. It can make corresponding decisions scientifically through arithmetic operations, which can greatly meet the needs of industry development and provide powerful information management functions, promote the good application and integration of The Internet of Things information within the scope of industry technology. Which facilitates the management and development of the industry [26]. Fig. 3 shows the basic architecture and application of the Internet of Things technology.

As can be seen from Fig. 3, the Internet of Things technology has developed rapidly and has powerful functions. The continuous enrichment of architecture makes its application scenarios more complex. At the same time, the information transmission is more accurate, and the mandatory operation is fast and convenient. With the continuous development of The Internet of Things technology, people have added a two-layer technical architecture, which includes an access layer and a support layer. The sensing layer is only responsible for reading object information and collecting data. The access layer is where users use terminal equipment to interact directly with the network through the access layer and meet different needs of users [27]. The support layer is responsible for data processing, and it transmits the processed information data to the application layer through the interface.

In the application process of the Internet of Things, it has the following characteristics:

a. Tight safety and controllability. Protect users' privacy information and prevent network attacks.

b. Integrated sensor and high frequency update rate. Different types of sensor information are collected and output formats are converted, and continuous high-frequency information updates are maintained.

c. wide application domain specificity. The Internet of Things technology is specialized in various fields.

d. High stability and reliability. Stable transmission and reliable accuracy of equipment information can be maintained in any complex scene.

e. Intelligent monitoring and control. Intelligent monitoring is realized by combining with sensors.

At present, the application of the Internet of Things mainly focuses on management and control in the fields of aerospace, public transportation, intelligent agriculture and logistics express delivery [28]. For example, the Internet of Things technology is used to monitor the real-time information of aviation components and effectively control internal performance and quality. The Internet of Things technology is used to accurately obtain vehicle information and route information, and ensure travel efficiency and safety. The Internet of Things technology is used to monitor the growth conditions of crops, which is convenient for users to determine the appropriate planting conditions and time. The Internet of Things technology can be used to realize the information transmission and positioning of logistics express delivery.

B. DESIGN OF INTELLIGENT MONITORING SYSTEM

According to the athletes' physical fitness test content and training program output, the intelligent monitoring system designed in this paper needs to collect, transmit and process the athletes' sports data in real-time. Which transmits the athletes' actual physical fitness status to the terminal. At the same time, it also needs to have corresponding training programs for users to choose. The principles followed in the system design process are:

a. The system is functionally complete.

b. The system is easy to use.

c. The system has maintainability and expandability.

d. The system has high security.

In principle, the development of system functions should meet the needs of users, constantly update the system, upgrade and maintain the wrong and imperfect contents. And they prevent external attacks by setting up a permission mechanism to avoid the disclosure of personal information. In the application process of intelligent monitoring system, the core technology and hardware equipment play an irreplaceable role.

1) CORE TECHNOLOGY

a: WIRELESS SENSOR TECHNOLOGY

Wireless sensor technology is a wireless network formed by combining a certain number of sensors through logical modes. In the application environment, it can intelligently collect the data of connected objects, and transmit the obtained results to the receiver at the other end of the network. Its function corresponds to the perception layer in the Internet of Things platform. Through monitoring the athletes' heart rate, pulse, blood pressure and other physical factors, it is transmitted to the Internet of Things platform through the network, which is convenient for the next data processing and analysis.

b: RFID TECHNOLOGY

RFID technology can be applied to the Internet of Things to carry out specific identification, which collects and tracks application target data by setting up electronic tags [29]. Through the technology, athletes' physical fitness monitoring information can be stored for a long time. And it can be directly retrieved and analyzed during the next monitoring, so as to ensure that athletes' real information is properly managed. At the same time, RFID technology can be combined with wireless sensing technology to quickly monitor athletes' physical fitness.

c: NETWORK COMMUNICATION TECHNOLOGY

At present, TCP/IP protocol can be widely used in many fields. Because IP is unique, various IP-based transactions can be interoperated under different network conditions under the same protocol standard. Therefore, through the same protocol standard all fields connect IP together to realize seamless convergence of IP. Then the information is analyzed and processed by software. Finally sharing and calling are realized.

d: HTTP PROTOCOL TECHNOLOGY

As the mainstream standard of WEB data transmission, HTTP is relatively simple to use, stable and efficient. HTTP is a text transmission protocol. It also is suitable for distributed hypermedia information systems [30]. Therefore, a connection is established between the server and the client based on TCP protocol to realize data transmission. HTTP is simple, fast, flexible, connectionless and stateless.

The combination of the above core technologies is integrated into the intelligent monitoring system to ensure the collection, storage and analysis of monitoring data, so that athletes and coaches could receive accurate physical fitness testing information.

2) HARDWARE EQUIPMENT

As the main body of hardware equipment, portable sensors are mostly designed in wearable equipment. They mainly realize motion monitoring through gyroscopes, GPS, ambient light sensors, skin temperature sensors and optical heart rate sensors. The coarse data collected by the acceleration sensor uses the first-order low-pass filter with a cut-off frequency of 0.25Hz to filter out the data fluctuation and distortion points existing in the continuous data sequence. Thus it reduces noise interference and improving the accuracy of the data to dynamically control the motion state of the movers in real-time. Gait judgment is completed according to threshold judgment and time window monitoring. Through gait mechanism of human body movement, acceleration in different dimensions is calculated by using composite acceleration values. Step recording and energy conversion algorithms are designed and completed. The portable sensor can monitor information data such as heart rate, number of exercise steps, calories, etc. At the same time, it should use the network or Bluetooth to keep the data synchronized and transmit it to the platform in real-time.

In the Internet of Things architecture, the cloud platform is the data center of the system. Its function is to analyze and store the data uploaded to the network database, and can display it in the form of user visualization. User management of cloud platform is used to distinguish different users and corresponding devices. They store information through association tables and provide interface functions to facilitate users to log in. With the increase of the number of devices and user information, the cloud platform can carry out effective classification management and storage, which is the basis of system operation. At the same time, it should ensure that it can be efficiently processed and accessed. The physical fitness intelligent monitoring system based on the Internet of Things technology is designed, which is shown in Fig. 4.

As shown in Fig. 4, the system uses portable sensors as task carriers, which uploads them to visual equipment through wireless networks, and feeds back the core information of physical fitness to users. So that they can specify corresponding training schemes. The system fundamentally removes the disadvantages of traditional manual management, and realizes low data storage cost, large storage quantity, convenient query and retrieval, high data security, good data confidentiality and high data reliability.

IV. PHYSICAL INTELLIGENCE EVALUATION BASED ON IMPROVED BP NEURAL NETWORK

According to the information obtained by the physical fitness intelligent monitoring system, the intelligent algorithm is used to carry out high-efficiency and high-precision evaluation and prediction. The final analysis result is sent to the terminal equipment. At the same time, the corresponding

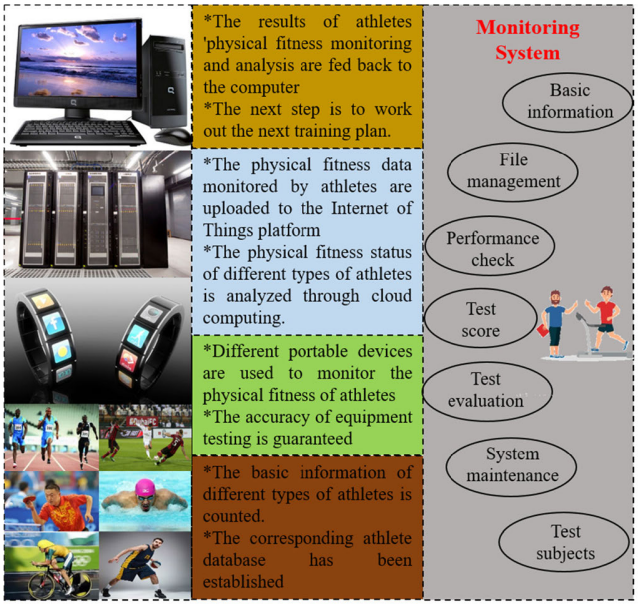

FIGURE 4. The flow chart of the intelligent physical fitness monitoring system.

training scheme is available for the user to select or modify on this basis. In the process of selecting the algorithm, this paper takes into account that coaches distinguish the physical fitness status of athletes and the physical fitness trend of later training according to monitoring data. The relationship between monitoring data and state evaluation results is difficult to describe directly, BP neural network can be used for nonlinear approximation.

A. LEARNING MECHANISM OF BP NEURAL NETWORK

The origin of BP neural network is to simulate the reaction process of human brain neurons to external stimulation signals. Based on multilayer perceptron, combined with signal forward propagation and error reverse adjustment. An intelligent network prediction model for processing nonlinear information can be effectively established on the basis of repeated learning [31]–[33].

The structure of BP neural network consists of input layer, hidden layer and output layer. The weight coefficient of hidden layer directly affects the overall performance of neural network. A complete learning mechanism includes forward propagation of signals, backward propagation of errors, memory training and learning convergence. In a learning process, input samples are processed layer by layer from the input layer through hidden units, and then passed through all hidden layers before being transferred to the output layer. In the process of layer-by-layer processing, the state of each layer of neurons only affects the state of the next layer of neurons. The output layer compares the actual output with the expected output, and if the output layer does not get the expected output value, it enters the reverse propagation process. In reverse propagation, the error signal is returned in reverse according to the original forward propagation path, the error between the actual output and the expected output is calculated recursively layer by layer. The weight coefficient of each neuron in each hidden layer is continuously adjusted to minimize the error signal [34], [35].

The structure of BP neural network consists of input layer, hidden layer and output layer. The weight coefficient of hidden layer directly affects the overall performance of neural network. A complete learning mechanism includes forward propagation of signals, backward propagation of errors, memory training and learning convergence. In a learning process, input samples are processed layer by layer from the input layer through hidden units, and then passed through all hidden layers before being transferred to the output layer. In the process of layer-by-layer processing, the state of each layer of neurons only affects the state of the next layer of neurons. The output layer compares the actual output with the expected output, and if the output layer does not get the expected output value, it enters the reverse propagation process. In reverse propagation, the error signal is returned in reverse according to the original forward propagation path, the error between the actual output and the expected output is calculated recursively layer by layer. The weight coefficient of each neuron in each hidden layer is continuously adjusted to minimize the error signal [34], [35].

1) FORWARD PROPAGATION OF SIGNALS

In the formula shown in Table 1, $i = 1, \cdots, n, j = 1, \cdots, p$, $t = 1, \cdots, q$, the activation function $f(\cdot)$ generally adopts Sigmoid function, then the input and output formulas of the hidden layer are respectively:

$$S_j^k = \sum_{i=1}^{n} w_{ij} x_i - \theta_j \tag{1}$$

$$b_j^k = f(S_j^k) = \frac{1}{1 + e^{-S_j^k}} \tag{2}$$

The input and output formulas of the output layer are:

$$L_j^k = \sum_{j=1}^{p} v_{jt} b_j - \gamma_t \tag{3}$$

$$C_t^k = f(L_t^k) = \frac{1}{1 + e^{-L_t^k}} \tag{4}$$

2) BACK PROPAGATION OF ERRORS

In the process of error back propagation, the weights and thresholds of each layer are corrected according to the principle of gradient descent. The mean square error between the expected value and the actual value of the neural network is as follows:

$$E_k = \frac{1}{2} \sum_{t=1}^{q} (Y_t^k - C_t^k)^2 \tag{5}$$

In the formula, $\frac{\partial E_k}{\partial v_{jt}} = \frac{\partial E_k}{\partial C_t} \frac{\partial C_k}{\partial v_{jt}} = -\delta_t^k C_t (1 - C_t) b_j$, which indicates the intensity of influence of the change of neural network weight on mean square error. Based on the principle

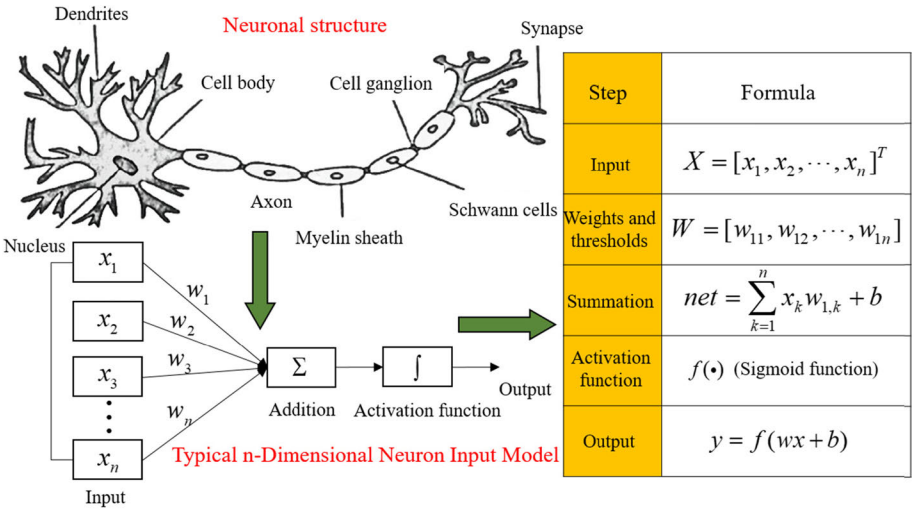

FIGURE 5. Structural sketch of the neuron mode.

TABLE 1. Input and output of each layer of BP neural network.

	Input Node	Output Node	Threshold	Weights	Activation function
Input Layer	$X_k=(x_1,\cdots,x_n)$	$Y_k=(y_1,\cdots,y_q)$		$\{w_{ij}\}$ ①	
Hidden Layer	$S_k=(s_1,\cdots,s_p)$	$B_k=(b_1,\cdots,b_p)$	$\{\theta_j\}$	$\{v_{jt}\}$ ②	$f(\bullet)$
Output Layer	$L_k=(l_1,\cdots,l_q)$	$C_k=(c_1,\cdots,c_q)$	$\{\gamma_i\}$		

①Represents the connection weights between the input layer and the hidden layer
②Represents the connection weights between the hidden layer and the output layer

of gradient descent, the negative ratio of the corrections Δv_{jt} and $\frac{\partial E_k}{\partial v_{jt}}$ of network weights is the same. Then:

$$\Delta v_{jt}=-\alpha(\frac{\partial E_k}{\partial v_{jt}})=-\alpha\delta_t^k C_t(1-C_t)b_j=\alpha d_t^k b_j \quad (6)$$

In the formula, $d_t^k=-\delta_t^k C_t(1-C_t)=\frac{\partial E_k}{\partial \gamma_t}=\frac{\partial E_k}{\partial C_t}\frac{\partial C_k}{\partial L_t}\frac{\partial L_t}{\partial \gamma_t}$, which represents the influence intensity of the neural network error change output result, and the threshold correction amount of each node in the output layer is:

$$\Delta\gamma_t=-\alpha(\frac{\partial E_k}{\partial \gamma_t})=-\alpha d_t^k \quad (7)$$

Similarly, the change of connection weight from the hidden layer to the input layer is as follows:

$$\Delta w_{ij}=-\beta(\frac{\partial E_k}{\partial w_{ij}})=-\beta(\sum_{t=1}^{q}\frac{\partial E_k}{\partial C_t}\frac{\partial C_k}{\partial L_t}\frac{\partial L_t}{\partial b_t})\frac{\partial b_j}{\partial S_j}\frac{\partial S_j}{\partial w_{ij}}=\beta e_j\alpha i \quad (8)$$

The threshold change amount of the hidden layer is:

$$\Delta\theta_j=-\beta(\frac{\partial E_k}{\partial \theta_j})=-\beta(\sum_{t=1}^{q}\frac{\partial E_k}{\partial C_t}\frac{\partial C_k}{\partial L_t}\frac{\partial L_t}{\partial b_t})\frac{\partial b_j}{\partial S_j}\frac{\partial S_j}{\partial w_{ij}}=-\beta e_j \quad (9)$$

3) LEARNING CONVERGENCE OF MEMORY TRAINING

When the error between the expected value and the output value satisfies the accuracy, the memory training is stopped. Inputting the original data to be tested into the neural network, which can be used for identification and prediction, and could generate output results by using the above learning rules.

BP neural network has strong fault tolerance, self-learning and self-adaptation capabilities. However, it also has obvious defects. When the training samples are noisy, the prediction accuracy will decrease. The convergence speed of network training is slow and it is easy to fall into local minima. Improper selection of network structure leads to reduction of generalization ability [36]. These are all problems that are easy to occur in the training and learning process of BP neural network, so this paper improves the above three defects.

B. IMPROVED BP NEURAL NETWORK

Aiming at the improvement of BP neural network, different denoising and intelligent optimization algorithms are introduced to make up for the defects. Firstly, the denoising algorithm is used to preprocess the original sample data, then the intelligent optimization algorithm is used to optimize the weights and thresholds in the neural network model. Finally,

the sample data after denoising is input into the optimized neural network prediction model.

In this paper, wavelet analysis is used to denoise, the essence of which is to retain the wavelet coefficients of effective signals to the maximum extent and remove the wavelet coefficients of noise [37]. At the same time, the smoothness and similarity of the original signal should be preserved as much as possible in the denoising process, indicating that the variance estimation of the signal before and after denoising is the minimum value in the worst case. Wavelet analysis has a strong denoising ability. By selecting appropriate wavelet basis functions, low-frequency and high-frequency components are denoised respectively, and the denoised data are reconstructed. When combined with other prediction models, wavelet analysis can greatly improve prediction accuracy and obtain better combined prediction performance.

The steps of the wavelet analysis method are to select the appropriate wavelet basis function, carry out wavelet decomposition on the original sample to obtain wavelet coefficients of each layer, and adopt soft threshold method to process the wavelet coefficients to minimize the maximum mean square error of the estimated signal. Finally, the denoised wavelet coefficients are subjected to wavelet reconstruction to obtain denoised sample data.

When selecting intelligent optimization algorithm, particle swarm optimization (PSO) is used to optimize the threshold and weight in the BP neural network. PSO is the most classical method in neural network optimization [38], [39]. The neural network optimized by particle swarm algorithm has faster convergence speed, which makes the trained network more in line with the actual requirements. In the optimization process, the dimension of each particle in the particle swarm is the system parameter of the neural network, and the optimal parameter is found through global search and optimization to complete the training. The basic steps are:

a. Initializing parameters such as velocity and position of particles in the particle swarm;

Assuming that the initial population consists of particles, representing candidate solutions, defines the search space as a -dimensional variable, then the position and velocity of the particle are:

$$\begin{cases} X_i = [X_{i1}, X_{i2}, \cdots, X_{id}]^T \\ V_i = [V_{i1}, V_{i2}, \cdots, V_{id}] \end{cases} \tag{10}$$

b. The objective function value and the fitness of each particle are calculated. The threshold and weight of the neural network are taken as the objective function, and the absolute error between the expected and predicted output is taken as the individual fitness;

c. The velocity and position of each particle are updated, and the adaptive inertia is introduced into the particle swarm optimization to adjust the inertia weight nonlinearly. The updating formulas for the velocity and position of the next generation of particles are as follows:

$$\begin{cases} V_{id}(t+1) = wV_{id}(t+1) + c_1N_1(P_{id}(t+1) \\ -X_{id}(t+1) + c_2N_2(P_{gd}(t+1) - X_{id}(t+1)) \\ X_{id}(t+1) = X_{id}(t) + V_{id}(t+1) \end{cases} \tag{11}$$

In the formula, is the number of iterations, and are the acceleration coefficients, is the inertia weight coefficient, and are random numbers between 0 and 1, and represent the velocity and position of the, and represent the optimal position of the current particle search and the optimal position of the whole particle swarm search, respectively.

d. The fitness of each particle after velocity and position updating is calculated to obtain the local and global optimal values after updating. Then the optimal threshold and weight of the neural network are obtained.

C. APPLICATION OF BP NEURAL NETWORK IN PHYSICAL INTELLIGENCE ANALYSIS

Firstly, the athletes' physical fitness monitoring data are denoised by wavelet transform. The denoised data are used as the input of BP neural network. The number of nodes in the input layer depends on the dimension of the data source, such as the athletes' physical fitness index plus gender, age, height and weight. The number of nodes in the output layer is 3, which are respectively poor, average and good. The number of nodes in the hidden layer affects the learning time and training effect. Generally, the formula is used to determine the number of nodes. Finally, the number of nodes is determined to be 6. The network performance is relatively stable. At the same time, the threshold and weight values in the network structure are taken as the objective functions in the particle swarm, and the error values of expected output and predicted output are taken as fitness functions. The optimal solution is obtained through continuous optimization calculation.

V. EXAMPLE VERIFICATION

For competitive sports, the ultimate goal of sports training is to create excellent sports results, and the physical fitness of athletes is the most basic and controllable factor to improve competitive ability. This paper establishes the index system of vertical jump, fast leg raising, sitting forward, height, chest circumference, constitution percentage, YOYO interval endurance running and other factors. By using the data of a certain country's football long-distance mobilization, BP network is trained, and then using the data in the literature [40], as shown in Table 2, BP network and PSO-BP network are tested respectively.

It can be seen from Fig.6 and Fig.7 that the training speed of optimized BP network is much higher than that before optimization. Moreover, when the training reaches about 38 steps, the mean square error of the optimized neural network reaches $8.3164 \times 10-6$, while that of the pre-optimized neural network reaches $9.9408 \times 10 - 6$ at 389 steps, which reflects the circumference, constitution percentage, YOYO interval endurance running and other factors. By using the

TABLE 2. Test data.

Index	1	2	3	4	5	6	7	8	9	10	11	12	Score
1	56	59	33.2	0	8.89	50	1.32	3.38	181.8	100	4.1	4320	100
2	50.55	55	23.6	1.12	9.34	47	1.44	3.88	178.2	91.24	6.41	3917	85
3	49.56	54	22.0	1.84	9.48	46	1.48	3.96	185.3	89.97	7.39	3753	80
4	48.56	52	20.3	2.55	9.61	45	1.53	4.03	176.5	88.69	8.38	3589	75
5	47.56	51	18.7	3.27	9.74	44	1.57	4.1	174.7	87.41	9.36	3425	70
6	46.56	50	17.0	3.99	9.87	43	1.62	4.17	187.1	86.13	10.35	3261	65
7	44.57	48	13.8	5.42	10.14	41	1.71	4.32	188.8	83.58	12.32	2933	55
8	42.57	45	10.5	6.86	10.4	38	1.8	4.46	169.4	81.02	14.29	2605	45
9	41.58	44	8.8	7.58	10.54	36	1.84	4.54	190.6	79.75	15.27	2441	40
10	35.59	37	-1.0	11.88	11.33	26	2.11	4.97	160.5	72.08	21.18	1540	10

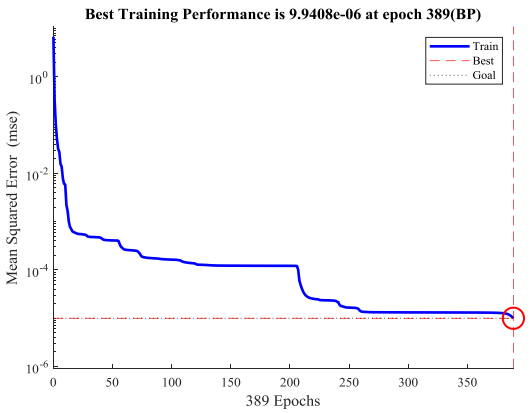

FIGURE 6. Training process of BP network before optimization.

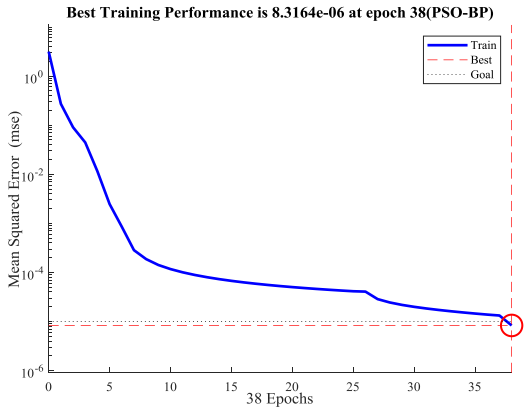

FIGURE 7. Training process of optimized BP network.

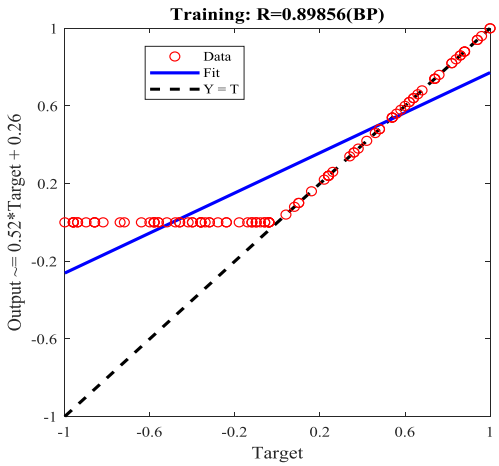

FIGURE 8. Regression diagram of BP network between output and target.

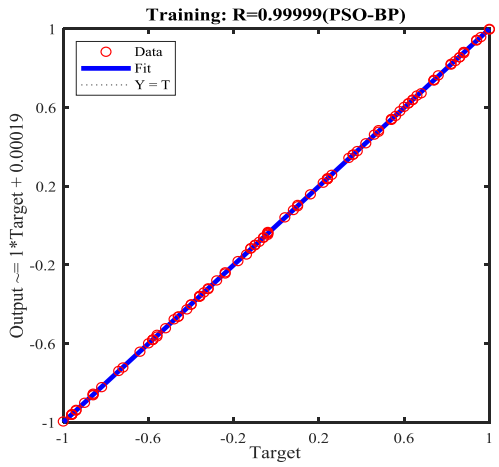

FIGURE 9. Regression diagram of PSO-BP network between output and target.

data of a certain country's football long-distance mobilization, BP network is trained, and then using the data in the literature [40], as shown in Table 2, BP network and PSO-BP network are tested respectively.

It can be seen from Fig.6 and Fig.7 that the training speed of optimized BP network is much higher than that before optimization. Moreover, when the training reaches about 38 steps, the mean square error of the optimized neural network reaches $8.3164 \times 10-6$, while that of the pre-optimized neural network reaches $9.9408 \times 10 - 6$ at 389 steps, which reflects the high efficiency and accuracy of the BP neural network after particle swarm optimization.

Fig.8 and Fig.9 respectively show the relationship between BP network output and target before and after optimization. R value indicates the strength of linear correlation between output and target. The closer R value is to 1, the stronger the

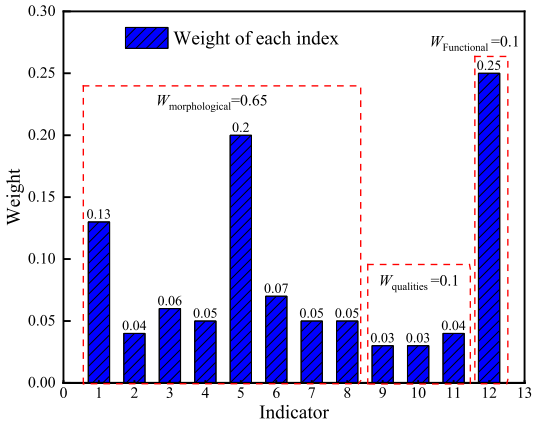

FIGURE 10. Weights optimized by PSO.

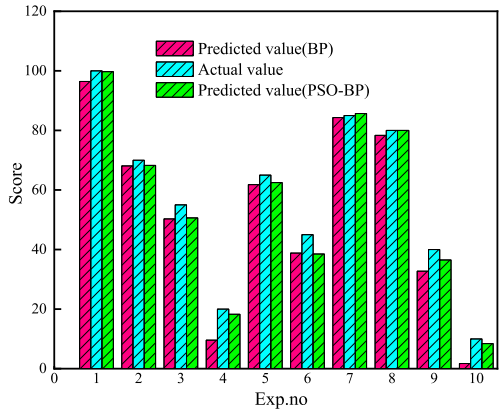

FIGURE 11. Comparison of BP and PSO-BP predictions.

linear correlation between network output value and target value is. The closer the R value is to 0, the weaker the linear correlation between the network output value and the target value. In Fig. 7, the R value of BP network is 0.89856, and in Fig.8, the R value of optimized BP network is 0.99999, indicating that the optimized BP network is more accurate in expressing the regression relationship between output and target.

Fig. 10 shows the weight value of BP network obtained by PSO optimization, and Fig.11 shows the comparison between predicted value and actual value of BP and PSO-BP network. It can be seen from Fig.11 that the prediction accuracy of optimized BP network is significantly better than that of optimized BP network. Through calculation, the average relative error of BP network prediction is 19%, and the average relative error of BP network prediction after PSO optimization is 6.3%, indicating that the BP network after PSO optimization greatly improves the accuracy of prediction.

VI. CONCLUSION

Aiming at the current demand of smartphone popularization and athlete training monitoring, this paper designs an intelligent monitoring system of physical fitness based on The Internet of Things technology. By selecting such factors as Vertical jump, Fast high leg lifts, Sit and Reach, Height, Bust, Percentage of body fat, YOYO interval endurance run et al, uses RFID technology to mark different athletes, and uses BP optimized by particle swarm optimization. The network method establishes the evaluation model of athlete's physical condition. We draw a conclusion by simulation:

a. From three aspects of athlete's physical fitness, shape and function, the index system of athlete's physical fitness evaluation is constructed by choosing such factors as Vertical jump, Fast high leg lifts, Sit and Reach, Height, Bust, Percentage of body fat, YOYO interval endurance run et al, which comprehensively reflects the athlete's physical fitness condition.

b. This paper systematically introduces the relationship between the Internet of Things technology and athlete physical fitness detection, and designs an intelligent physical fitness monitoring system based on the Internet of Things technology.

c. According to the information obtained by the intelligent physical fitness monitoring system, Using BP network to carry out high-efficiency and high-precision evaluation and prediction, and the final analysis results are put into the terminal equipment to realize the detection and evaluation of athletes' physical fitness.

d. Exploring the performance of BP network and particle swarm optimization BP network by simulation experiments. The results show that the optimized BP network has higher efficiency and accuracy, and is obviously superior to the traditional BP network in the evaluation and prediction of athletes 'physical fitness.

REFERENCES

[1] B. Langhammer and J. K. Stanghelle, "Senior fitness test; a useful tool to measure physical fitness in persons with acquired brain injury," *Brain Injury*, vol. 33, no. 2, pp. 183–188, 2019.
[2] D. S. Cameron, E. J. Bertenshaw, and P. Sheeran, "Positive affect and physical activity: Testing effects on goal setting, activation, prioritisation, and attainment," *Psychol Health*, vol. 33, no. 2, pp. 258–274, 2018.
[3] J. E. Simon and C. L. Docherty, "The impact of previous athletic experience on current physical fitness in former collegiate athletes and noncollegiate athletes," *Sports Health*, vol. 9, no. 5, pp. 462–468, May 2017.
[4] T. Kietzmann, "Effects of plyometric training on physical fitness in prepuberal soccer athletes," *Int. J. Sports Med.*, vol. 38, no. 5, pp. 370–377, May 2017.
[5] G. S. Zhao, G. R. Chen, and J. B., "The physical fitness test model and standard of sanda athletes," *J. Shanghai Inst. Phys. Educ.*, vol. 4, pp. 65–69, Nov. 2002.
[6] C. T. Woods, I. Mckeown, J. Keogh, and S. Robertson, "The association between fundamental athletic movements and physical fitness in elite junior Australian footballers," *J. Sports Sci.*, vol. 36, no. 4, pp. 445–450, 2018.
[7] P. Yang, "Development and design of database system for physical fitness test of table tennis players," *Automat. Instrum.*, vol. 1, pp. 50–51, Sep. 2017.
[8] M. J. Miller, J. Kutcher, and K. L. Adams, "Effect of pregnancy on performance of a standardized physical fitness test," *Military Med.*, vol. 182, no. 11, pp. 1859–1863, Nov./Dec. 2017.
[9] K. C. Tseng, A. M.-K. Wong, C.-L. Hsu, T.-H. Tsai, C.-M. Han, and M.-R. Lee, "The IFIT: An integrated physical fitness testing system to evaluate the degree of physical fitness of the elderly," *IEEE Trans. Biomed. Eng.*, vol. 60, no. 1, pp. 184–188, Jan. 2013.
[10] C. C. Huang, H. M. Liu, and C. L. Huang, "Intelligent scheduling of execution for customized physical fitness and healthcare system," *Technol. Health Care*, vol. 24, no. s1, pp. 385–392, 2015.

[11] A. Puchi, T. M. Dabbas, and C. Riccour, "Evaluation of physical capacities of obese children: The use of a test for cardiovascular fitness in their follow up: P036," *Pediatric Res.*, vol. 60, no. 5, p. 637, Nov. 2006.
[12] F. B. Ortega, C. Cadenas-Sánchez, G. Sánchez-Delgado, J. Mora-González, B. Martínez-Téllez, E. G. Artero, J. Castro-Piñero, I. Labayen, P. Chillón, M. Löf, and J. R. Ruiz, "Systematic review and proposal of a field-based physical fitness-test battery in preschool children: The PREFIT battery," *Sports Med.*, vol. 45, no. 4, pp. 533–555, Apr. 2015.
[13] D. Leyk, U. Rohde, W. Gorges, M. Ridder, M. Wunderlich, C. Dinklage, A. Sievert, T. Rüther, and D. Essfeld, "Physical performance, body weight and BMI of young adults in Germany 2000-2004: Results of the physical-fitness-test study," *Int. J. Sports Med.*, vol. 27, no. 8, pp. 642–647, Aug. 2006.
[14] T. R. Kuklo, J. E. Tis, and L. K. Moores, "Fatal rhabdomyolysis with bilateral gluteal, thigh, and leg compartment syndrome after the army physical fitness test," *Amer. J. Sports Med.*, vol. 28, no. 1, pp. 112–116, Jan. 2000.
[15] I. Fjortoft, A. V. Pedersen, H. Sigmundsson, and B. Vereijken, "Measuring physical fitness in children who are 5 to 12 years old with a test battery that is functional and easy to administer," *Phys. Therapy*, vol. 91, no. 7, pp. 1087–1095, Jul. 2011.
[16] M. Mucke, L. Sebastian, C. Flora, and M. Gerber, "Influence of regular physical activity and fitness on stress reactivity as measured with the trier social stress test protocol: A systematic review," *Sports Med.*, vol. 48, no. 11, pp. 2607–2622, Nov. 2018.
[17] F. B. Ortega, E. G. Artero, and J. R. Ruiz, "Physical fitness levels among European adolescents: The HELENA study," *Brit. J. Sports Med.*, vol. 45, nos. 20–29, Jan. 2011.
[18] R. Ranson, G. Stratton, and S. R. Taylor, "Digit ratio (2D:4D) and physical fitness (Eurofit test battery) in school children," *Early Hum. Develop.*, vol. 91, no. 5, pp. 327–331, May 2015.
[19] M. S. Molloy, C. M. Robertson, and G. R. Ciottone, "Chester step test as a reliable, reproducible method of assessing physical fitness of disaster deployment personnel," *Southern Med. J.*, vol. 110, no. 8, pp. 494–496, 2017.
[20] A. Turner, G. Lambert, and S. Torres, "Cortisol and catecholamine responses to Trier Social Stress Test (TSST) are independent of physical fitness in women aged 30–50 years," *Psychoneuroendocrinology*, vol. 61, pp. 72–73, Sep. 2015.
[21] L. Wu, X. Du, W. Wang, and B. Lin, "An out-of-band authentication scheme for Internet of Things using blockchain technology," in *Proc. Int. Conf. Comput.*, Mar. 2018, vol. 38, no. 2, pp. 293–298.
[22] D. Despa, G. F. Nama, M. A. Muhammad, and K. Anwar, "The implementation Internet of Things(IoT) technology in real time monitoring of electrical quantities," *IOP Conf., Mater. Sci. Eng.*, vol. 335, Apr. 2018, Art. no. 012063.
[23] H. Nagano, "Big data, information and communication technology, artificial intelligence, Internet of Things: How important are they for gastroenterological surgery?" *Ann. Gastroenterolog. Surg.*, vol. 2, no. 3, p. 166, May 2018.
[24] A. M. C. Souza and J. R. A. Amazonas, "An outlier detect algorithm using big data processing and Internet of Things architecture," *Procedia Comput. Sci.*, vol. 52, pp. 1010–1015, Jan. 2015.
[25] H. S. Ning and Z. Wang, "Future Internet of Things architecture: Like mankind neural system or social organization framework?" *IEEE Commun. Lett.*, vol. 15, no. 4, pp. 461–463, Apr. 2011.
[26] J. Ni, K. Zhang, X. Lin, and X. S. Shen, "Securing fog computing for Internet of Things applications: Challenges and solutions," *IEEE Commun. Surveys Tuts.*, vol. 20, no. 1, pp. 601–628, 1st Quart., 2018.
[27] G. C. Nobre and E. Tavares, "Scientific literature analysis on big data and Internet of Things applications on circular economy: A bibliometric study," *Scientometrics*, vol. 111, no. 1, pp. 463–492, Apr. 2017.
[28] E. Rapti, A. Karageorgos, C. Houstis, and E. Houstis, "Decentralized service discovery and selection in Internet of Things applications based on artificial potential fields," *Service Oriented Comput. Appl.*, vol. 11, no. 1, pp. 75–86, Mar. 2017.
[29] R. Want, "An introduction to RFID technology," *IEEE Pervasive Comput.*, vol. 5, no. 1, pp. 25–33, Jan./Mar. 2006.
[30] R. W. Treskes, L. A. van Winden, N. van Keulen, D. E. Atsma, E. T. van der Velde, E. van den Akker-van Marle, B. Mertens, and M. J. Schalij, "Using Smart Technology to Improve Outcomes in Myocardial Infarction Patients: Rationale and Design of a Protocol for a Randomized Controlled Trial, The Box," *JMIR Res. Protocols*, vol. 6, no. 9, p. e186, 2017.
[31] H. Fei and L. Zhang, "Prediction model of end-point phosphorus content in BOF steelmaking process based on PCA and BP neural network," *J. Process Control*, vol. 66, pp. 51–58, Jun. 2018.
[32] X. Tan, Z. Ji, and Y. Zhang, "Non-invasive continuous blood pressure measurement based on mean impact value method, BP neural network, and genetic algorithm," *Technol. health Care*, vol. 26, no. 6, pp. 87–101, May 2018.
[33] M. Liu and J. Shi, "A cellular automata traffic flow model combined with a BP neural network based microscopic lane changing decision model," *J. Intell. Transp. Syst.*, vol. 23, no. 4, pp. 309–318, 2019.
[34] H. Jin, S. Wu, and Y. Peng, "Prediction of contact fatigue life of alloy cast steel rolls using back-propagation neural network," *J. Mater. Eng. Perform.*, vol. 22, no. 12, pp. 3631–3638, Dec. 2013.
[35] J. Li, X. H. Wu, and C. H. Qin, "The design of image compression with BP neural network based on the dynamic adjusting hidden layer nodes," *Adv. Mater. Res.*, vol. 433, pp. 3797–3801, Jan. 2012.
[36] X. Yu, Y. Fu, P. Li, and Y. Zhang, "Fault-tolerant aircraft control based on self-constructing fuzzy neural networks and multivariable SMC under actuator faults," *IEEE Trans. Fuzzy Syst.*, vol. 26, no. 4, pp. 2324–2335, Aug. 2018.
[37] H. Boubaker and S. A. Raza, "A wavelet analysis of mean and volatility spillovers between oil and BRICS stock markets," *Energy Econ.*, vol. 64, pp. 105–117, May 2017.
[38] H. Liu, Z. Cai, and Y. Wang, "Hybridizing particle swarm optimization with differential evolution for constrained numerical and engineering optimization," *Appl. Soft Comput.*, vol. 10, no. 2, pp. 629–640, Mar. 2010.
[39] S. Chatterjee, S. Sarkar, S. Hore, N. Dey, A. S. Ashour, and V. E. Balas, "Particle swarm optimization trained neural network for structural failure prediction of multistoried RC buildings," *Neural Comput. Appl.*, vol. 28, no. 8, pp. 2005–2016, Aug. 2017.
[40] Z. Chen, X. K. Chen, and C. X. Wang, "U17 analysis of football players' special sensitivity and endurance quality and establishment of evaluation grade," *J. Beijing Sport Univ.*, vol. 39, no. 11, pp. 112–118, Nov. 2016.

ZEJIANG HUANG was born in Longchang, Sichuan, China, in 1977. He received the B.S. degree in physical education from Beijing Sport University, Beijing, China, in 2001, and the M.S. degree in physical education and sports training from Chengdu Sport University, in 2018.

From 2001 to 2006, he was an Assistant lecturer of Sichuan Normal University, where he became the Lecturer, in 2006. In 2015, he became the Vice-Professor in physical education and sports training. His main research includes event teaching in track and field, and organization of marathon competition. He has over 20 articles in the professional publication, and has taken part in over 10 research projects. He has published one book about fitness training for athletics.

QINGGUO CHEN was born in Luzhou, Sichuan, in October 1981. He received the bachelor's degree in physical education from Beijing Normal University, in June 2004, the master's degree from Beijing Normal University, in 2007, and the Ph.D. degree in sports science from Beijing Sport University, in 2012.

Since 2007, he has been with the Physical Education College, Sichuan Normal University. In 2012, he passed the evaluation of intermediate titles. In 2014, he passed the evaluation of associate senior titles. He is currently a Vice-Professor. His main research field is the measurement and evaluation of the physical activity. He has published more than 20 articles, has presided over one international foundation, two foundations from provincial and ministerial and a number of prefectural-level foundations.

LIFENG ZHANG was born in Xinyang, Henan, China, in 1977. He received the B.S. degree in physical education from Wuhan Sport University, Wuhan, China, in 2000, the M.S. degree in physical education and sports training from Peking Sport University, in 2005, and the Ph.D. degree from Peking Sport University, in 2012.

From 2005 to 2012, he was an Assistant Lecturer with the Chengdu Sport Institute, where he became a Lecturer, in 2012. His main research interests include event teaching in track and field, fitness training for youth. He is one member of the China Sport Science Society (CSSS), and also a one chief member of the Second Class Society of CSSS. He was awarded for his outstanding performance in the forums and research in track and field, from 2010 to 2015.

XIAOHAI HU was born in Harbin, Heilongjiang, China, in 1977. He received the B.S. degree in physical education from Beijing Sport University, Beijing, China, in 2001, and the M.S. degree in physical education and sports training from Beijing Sport University, in 2011.

From 2001 to 2007, he was an Assistant Lecturer of Zhengzhou University, where he became a Lecturer, in 2007, and became the Vice-Professor in physical education and sports training with Zhengzhou University, in 2013. His main research interests include fitness training and rehabilitation training.